with pilot balloons, because the latter refer to the best flying weather and the former to conditions more or less disadvantageous.

There is no doubt that as pilot-balloon observations are multiplied frequency and velocity wind-roses for various levels in the free air will be constructed for other stations, but the data available are at present scanty, and several years must elapse before sufficient observations exist for reliable direct results at a network of stations.

An alternative method, which though indirect is at present much more feasible, is based on the theoretical study of the relations of wind force to pressure gradient. A synchronous pressure chart at mean sea level corresponds to a certain actual distribution of surface winds; it also represents by the direction and closeness of the isobars the "geostrophic" wind, which is what the wind would be were there no surface friction. In practice it is found that the theoretical wind based on the measurement of the isobars at sea level gives a good approximation—when numerous observations are considered—to the actual wind prevailing at a height of between 1,000 and 2,000 feet. Hence by measuring the gradient on a series of daily weather charts we can obtain tables or charts showing the frequency of geostrophic winds of different directions and velocities, and we may assume that these represent conditions at, say, 1,500 feet above ground.

Such a study of the geostrophic winds over London based on the 35 years, 1881–1915, of over 1,000 observations for each month, is published month by month in the *Meteorological Magazine*, and a similar study of the geostrophic winds over the North Atlantic is in progress, and the data have appeared in part on the pilot charts for that ocean. But much more than this needs to be done. The geostrophic winds need to be tabulated, not for isolated stations, but for a connected network of selected points. With a sufficiently close network the relationships of the geostrophic winds to geography and configuration can be made out and interpolation for any desired point will present no difficulty.

This program is perfectly feasible for the greater part of the northern hemisphere, including Egypt and India, also for Australia and the Argentine, but the work is laborious, as to provide a sufficient basis the daily weather charts for at least 10 years have to be examined and measured, and for its satisfactory accomplishment longer periods should be utilized so that international cooperation is advisable.

Two points must be remembered in connection with these pressure maps. The first is that as the air becomes less dense with increasing height, a definite barometric gradient causes winds with a proportionally greater velocity. The second is that the wind velocity corresponding to a definite gradient increases as the latitude decreases, until close to the Equator any measurable gradient at all causes theoretically infinite velocities, so that the calculation of gradient winds becomes impossible and between the latitudes of 20° north and south we must at present rely for our knowledge of the upper winds on direct observation and not on calculation.

Similar in principle, but far less laborious in practice, is the process of obtaining the *resultant* geostrophic wind. This is the result which would be obtained by averaging a large number of individual geostrophic winds at any place, the east winds being treated as negative west winds and the north winds as negative south winds. Practically the same result is obtained by measuring the average barometric gradient from a chart of mean pressure distribution. For the wind at a height of 1,000 or 1,500 feet it suffices to use a *good* detailed chart of the pressure at mean sea level, in which the isobars should be drawn for every millibar or millimeter on a projection which gives a reasonably uniform scale for different latitudes and longitudes. But for greater altitudes it is necessary to take into account the temperature of the air. For cold air is heavier than warm air, and hence in a column of cold air, pressure (i. e., weight of the overlying column of air) decreases more rapidly upwards than a column of warm air. For this reason pressure lapse with height is more rapid in higher than in lower latitudes, so that at a height of several kilometers there is in temperate and subtropical latitudes a well-marked poleward pressure gradient, causing the great preponderance of westerly winds at these levels.

Now it is found that except in very cold regions there is on the average a fairly uniform decrease of temperature from the surface upwards, amounting to about 6a per kilometer. On this basis, given a chart of the average distribution of pressure and temperature over any portion of the earth's surface, we may proceed to work upwards, calculating the pressure distribution at 1, 2, 3 kilometers, and so on, with reasonable accuracy up to 5 kilometers (16,000 feet), which is as a rule as high a level as aviators are likely to require for some time to come.

This process was first carried out by Teisserenc de Bort in connection with a study of the circulation of the atmosphere. He published charts showing the calculated isobars in January and July at a height of 4 kilometers,[11] and showed that they agreed well with the average direction of motion of cirrus clouds, though the latter are in general at a much higher level. No similar charts for the whole world have yet been published, but Col. H. G. Lyons has prepared [12] charts of the pressure distribution over the Mediterranean during January, April, July, and October at the 1, 2, 3, and 4 kilometer levels, and recently H. U. Sverdrup [13] has published mean annual maps of the eastern north Atlantic showing the topography of the isobaric surfaces of 1,000 mb., 900 mb., and so on up 300 mb. The latter form is unsuitable for the purposes of aviation but could be converted to the more usual form with little difficulty.

Thus we see that a good beginning has been made both along lines of research in the direct observation of kites and pilot balloons and in the study of geostrophic winds at various levels. The general lines of the atmospheric circulation are already charted and we have now to look forward to the gradual filling in of details, until we can construct charts with first hundreds and then a thousand or more of arrows representing the winds at various levels all over the world.

DISCUSSION.

By C. LE ROY MEISINGER.

While the paper above is very interesting in the suggestions it makes for researches which may be applied to the benefit of aviation in all parts of the world, it should be strongly emphasized that averages of the meteoro-

[11] Hildebrandsson, H. H., and L. Teisserenc de Bort.: *Les Bases de la météorologie dynamique*. Tome 2, p. 214.

[12] Monthly Meteorological Charts of Mediterranean Basin, M. O. 224, 2 ed. Introductory Sheet.

[13] Sverdrup, H. U.: Der nordatlantische Passat. *Veröff. Geophys. Inst. Univ.* Leipzig, Bd. 2, H. 1. Leipzig, 1917.

logical elements are extremely limited in their application. There is no denying the value of charts of the prevailing winds, and other auxiliary charts, in such undertakings as the preliminary laying out of air routes; but where the line of demarcation comes between climatological data and current conditions, there is indeed need to proceed with caution. The "ocean of air," as the author of the paper and others have chosen to call it, is a questionable figure of speech, because there is really very little in common in the characteristics of the aerial and aqueous oceans. Popular writers and lecturers convey the impression that there are great permanent currents sweeping through the atmosphere with the same incessant flow as the Gulf Stream or the Japan Current; the ideas thus conveyed are erroneous, for we know that, to altitudes within which flying will always be confined, there are no such streams or currents which are dependable at all times.

For that reason, it is believed that too much emphasis has been laid on the work of Rotch and Palmer, which the author mentions. True, this was the pioneer work, and as such it should be, and is, respected. But to-day there is a great deal more information upon which to base conclusions. Instead of Blue Hill and Lindenburg Observatories being the "most important" in collecting aerological data it is now to be remembered that the Blue Hill Observatory has not been making upper-air soundings for several years; hereas, the Weather Bureau is maintaining at the present time six kite stations which make frequent kite and pilot-balloon ascensions, and in addition, including aerological stations of the Army and Navy which cooperate with the Weather Bureau, there are 21, and during the hurricane season 24, pilot-balloon stations. It is evident that, with such activity, an immense amount of data has been compiled and is constantly being added to.

It should be recalled, also, in this connection, that the network of aerological stations in Europe at the present time is much closer than that in the United States, owing to the smaller sizes of the countries, and the consequently shorter distances between stations. For example, in Italy alone there are 30 aerological stations whose wind data to the height of 5,000 meters have been published for a long time.

The deduction of the resultant movement of the air from mean-pressure distribution upon the principle of the gradient wind would seem to be of greater value in discussing the general circulation of the atmosphere during certain periods than in conveying to the aviator an impression of the wind movement aloft. Charts and tables of the geostrophic wind, such as those published in the *Meteorological Magazine*, would, however, be of unquestioned value in determining the wind frequencies aloft. There would be other charts of a statistical nature which could be profitably used, such as those showing frequencies of winds above certain limiting speeds, or characteristic turning with altitude under different typical distributions of pressure and temperature at the surface. These would not only aid the aviator, but would perhaps assist the trained meteorologist even more in forming his judgment of probable conditions aloft, when he is unable to get current data.

But above all, in any discussion of such information as Mr. Brooks has suggested in his paper, the aviator, who is the ultimate consumer, must be warned very carefully indeed lest he misinterpret the significance of averages. He is very likely never to find the conditions aloft which his chart of prevailing winds shows; and if he does not realize this, he may not only be unpleasantly surprised in flight, but may be inclined to lose the respect and confidence which he may previously have had for the meteorologist who is trying to assist him.

The paper was actually suggested during the compilation of a bibliography of upper-air data, when it was thought that some account of the lines along which the available material was being utilized would be of interest. As the bibliography already included well over 100 cards, it was obviously impossible to deal with each separately, and the references were accordingly limited to data which had been summarized in a way presenting features of interest. At the time no summary of the data in the admirable Italian *Bollettino Aerologico* was known, but recently several discussions by Gamba have come to hand and references to them have been added.

I quite agree that the only good form of summary is one in which the direction frequencies are subdivided into velocity frequencies, but when this is done they are at least as useful as corresponding wind-roses over the sea surface, which are published in marine "pilot charts" and are readily understood by seamen. Such tables for the air over North America or Europe indicate that the aerial currents are variable (as are the marine currents in many parts of the ocean); in other places, as in the Trades or in southwest Asia, the air currents at certain levels have an extraordinary constancy, quite on a par with that of the great ocean currents.—*C. E. P. B.*